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AD313951	
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REPORT R-1516

TECHNICAL REPORT

EFFECT OF 20 MM FRAGMENT-SIMULATING PROJECTILE HARDNESS ON BALLISTIC RESISTANCE OF ALUMINUM-MAGNESIUM ALLOY ARMOR (U)

By

H. E. FATZINGER

and

A. J. KASE

FC

Ordnance Project No. TB4-005
DA Project No. 593-32-006

JULY 1959

REPORT R-1516

U.S. ARMY ORDNANCE

FRANKFORD ARSENAL

RESEARCH AND DEVELOPMENT GROUP

PHILADELPHIA 37, PA

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1744-1068-57

CODE SHEET

Symbol	Producer	Address
A	Aluminum Company of America	1200 Ring Building Washington 6, D. C.
B	Kaiser Aluminum and Chemical Co.	Spokane 69, Washington
C	Reynolds Metals Company, Inc.	4th & Canal Sts., Richmond, Virginia

Frankford Arsenal Report R-1516, July 1959
"EFFECT OF 20 mm FRAGMENT SIMULATING PROJECTILE HARDNESS ON BALLISTIC RESISTANCE OF ALUMINUM-MAGNESIUM ALLOY ARMOR (U),"
- H. E. Fatzinger and A. J. Kase

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REPORT R-1516

EFFECT OF 20 mm FRAGMENT-SIMULATING PROJECTILE HARDNESS ON BALLISTIC RESISTANCE OF ALUMINUM-MAGNESIUM ALLOY ARMOR (U)

July 1959

Ordnance Project No. TB4-005 DA Project No. 593-32-005

Prepared by

H. E. Fatzinger

H. E. FATZINGER
Chief
General Physics Section

A. J. Kase

A. J. KASE
Physicist

Reviewed by

E. R. THILO
Director
Physics Research Laboratory

H. MARKUS
Director
Metallurgy Research Laboratory

A. L. JAMIESON
Chief
Research Division

Approved by

C. C. FAWCETT
Deputy Chief
Pitman-Dunn Laboratories Group

For

A. R. CYR
Colonel, Ordnance Corps
Commanding

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Philadelphia 37, Pa.

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OBJECT

(U) To determine the effect of variations in 20 mm fragment-simulating projectile hardness on the ballistic resistance of aluminum-magnesium alloy armor

SUMMARY

~~(U)~~ Several aluminum-magnesium alloys ~~(5083-H113, 5083-H115, 5456-H321, and 5456-H322)~~ were tested to determine their ballistic resistance against penetration of 20 mm G2 fragment-simulating projectiles as a function of simulator hardness. Fragment simulator hardnesses of Rockwell C15 to 16, 21 to 23, 25 to 27, 29 to 31, 33 to 35, and 40 to 42 were used in these tests. Protection ballistic limits (PBL) were determined for 1 1/4 in. thick plates set at 45° obliquity.

~~(C)~~ It was found that the ballistic limits of the armor plates varied inversely with simulator hardness. For simulators of Rc 15 to 16 hardness, the plate PBL's were 660 to 890 fps higher than for those of Rc 33 to 35; for simulators of Rc 21 to 23 hardness, the PBL's were 415 to 900 fps higher than for those of Rc 40 to 42. A difference of several points in simulator hardness on either side of the specified range (Rc 29 to 31) may result in significantly different ballistic limits for the test condition investigated.

~~(U)~~ It is recommended that the fabricators of fragment-simulating projectiles be required to provide more uniform projectile lots so that 100 ~~percent~~ % hardness check by the user is not necessary. This may be accomplished by using through-hardening steel and heat treating procedures which will assure minimum decarburization.

AUTHORIZATION

W.D. 70405730-06-45002

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EFFECT OF 20 mm FRAGMENT-SIMULATING PROJECTILE HARDNESS ON BALLISTIC RESISTANCE OF ALUMINUM-MAGNESIUM ALLOY ARMOR (U)

INTRODUCTION

(C) The current armor ballistic requirements for the multipurpose lightweight (8-ton) airborne T113 class of vehicles are primarily for protection against penetration by high explosive shell fragments at 50 ft range and secondarily for protection against penetration by caliber .30 armor piercing projectiles at 100 yd range. For this class of vehicles, weight is more critical than armor protection. It is therefore intended to use weldable aluminum-magnesium alloy instead of steel to reduce weight and still obtain the ballistic protection afforded by steel armor. Certain types of aluminum alloy armor, such as 2024-T4, are known to provide better ballistic protection against shell fragments and small caliber AP projectiles than steel armor of equal weight. However, a disadvantage of some of these alloys is that they are not readily weldable.

(C) Work was therefore started in 1956 to test, ballistically a new series of weldable aluminum-magnesium alloys. Various plate thicknesses and target conditions that were investigated included 3/4, 1, 1 1/4, 1 1/2, and 1 3/4 in. thicknesses set at 0, 30, 45, and 60 degree obliquities. Caliber .50 and 20 mm G2 fragment-simulating projectiles (Watertown Arsenal design) and calibers .30 and .50 AP M2 projectiles were used in evalutating the ballistic resistance of various experimental aluminum-magnesium alloys supplied by the major aluminum producers. Since the major portion of the T113 vehicles* was originally scheduled to be armored with the 1 1/4 in. thickness, the majority of ballistic screening tests was conducted with this thickness. Results obtained in these screening tests and subsequent qualification and acceptance tests are described in Reference 1.** The test condition of 1 1/4 in. plate at 45° obliquity, with 20 mm fragment-simulating projectiles, showed the greatest difference in ballistic resistance among the various alloys. This test condition was therefore selected for subsequent qualification and acceptance tests.***

(C) In subsequent tests reproducibility difficulties were experienced; ballistic limits that had been obtained originally with certain plate

*These vehicles, however, will now be armored mostly with 1 1/2 and 1 3/4 in. thick plate.

**See attached REFERENCES.

***Because of reproducibility problems, qualification and acceptance tests are now being conducted at 0° obliquity, according to Reference 2.

lots and projectile lots could not be reproduced. While investigating the cause for these difficulties, hardness checks on sectioned specimens of current lots of 20 mm fragment simulators revealed variations from Rockwell C 24 to 34. The drawing for these projectiles specifies that the hardness should be Rockwell C 29 to 31.

(C) As a result of these tests it was decided to conduct an investigation to determine whether hardness variations in fragment-simulating projectiles affect their ballistic penetration performance. This report describes the results of this investigation.

MATERIALS

Projectiles

(U) Figure 1 shows a sketch of the 20 mm fragment simulator (G2) which was used in these tests. The simulators were obtained from Watertown Arsenal, which has a contract for procuring them.

(U) Analysis indicated that these simulators were made of 4130 steel of the composition shown in Table I.

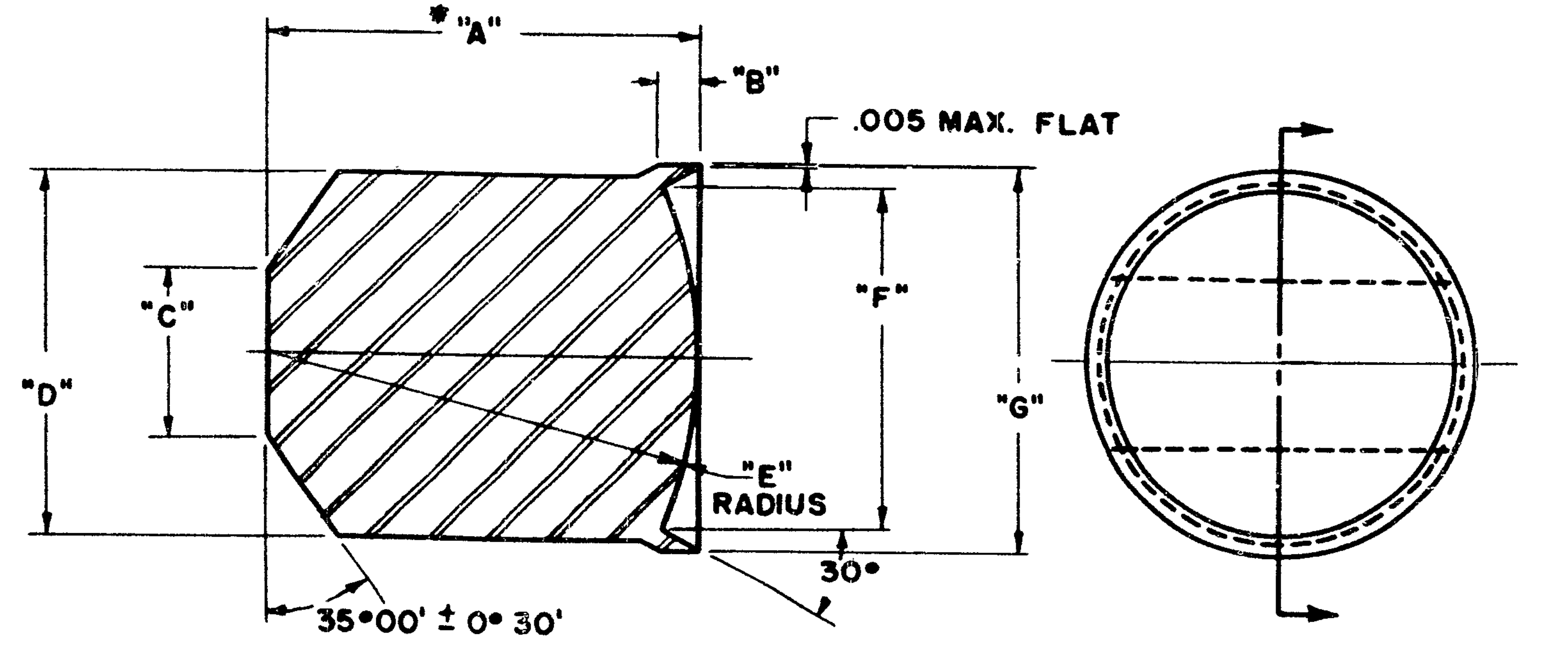
(U) TABLE I. Composition of 20 mm Fragment Simulators

Al	C	Cr	Cu	Mn	Mo	Ni	Si	V
0.02	0.31	0.97	0.07	0.53	0.25	0.07	0.25	0.01

(U) The as-received simulators were re-heat treated by austenitizing at 1600° F for 30 minutes, oil quenching to 250° F, and air cooling to room temperature. To obtain the various hardnesses desired, they were tempered in salt for one hour at the temperatures shown in Table II and then air cooled to room temperature. The simulators were segregated according to the hardness groups of Table III after a 100 percent hardness check on the bases from which the decarburized layers had been removed.

(C) TABLE II. Tempering Temperatures and Simulator Hardnesses

Tempering Temperature (°F)	Rc Hardness
1250	21 to 23
1150	25 to 27
1080	29 to 31
1000	33 to 35
800	40 to 42



STEEL-FINISH 32

* ADJUST LENGTH TO SECURE INDICATED WEIGHT
HARDNESS - Rc 29-31

SIZE	WEIGHT-GRAINS	"A"	"B"	"C"	"D"	"E"	"F"	"G"	DRAG COEF, k
CAL. .22	17.0 ± 0.5	.250	.025	.100	.215	.250	.200	.226	0.00620
CAL. .300	44.0 ± 0.5	.348	.034	.136	.296	.340	.273	.309	0.00455
CAL. .500	207.0 ± 1.0	.582	.058	.224	.495	.580	.460	.511	0.00274
CAL. 20MM	825.0 ± 4.0	.912	.091	.365	.784	.910	.740	823	0.00154

FRAGMENT-SIMULATING PROJECTILES

Figure 1. Fragment Simulator

(U) TABLE III. Mechanical Properties* of 1 1/4 in. Armor Plate

Alloy Plate			Longitudinal			Transverse		
			Strength (1000 psi)		Elongation (% in 2 in. Gage Length)	Strength (1000 psi)		Elongation (% in 2 in. Gage Length)
Type	Producer	Lot No.	Tensile	Yield		Tensile	Yield	
5456-H321	A	180-661	51.2	43.8	13.5	-	-	-
5456-H321	A	128-611	50.2	31.8	16.5	-	-	-
5083-H118-Sr	B	791547	47.7	38.9	15.0	45.6	32.7	17.0
5083-H118-Sr	B	791546	45.7	34.6	16.5	44.8	30.0	19.0
5083-Sr (8 3/4%)	B	791936	50.0	41.7	14.5	49.4	36.1	16.0
5083-H115	B	740530	46.6	38.2	15.7	-	-	-
5456-H322	C	GN7605	51.0	39.1	14.0	51.2	37.1	14.0
5083-H113	C	GN7711	48.1	38.3	14.0	48.3	36.7	13.0
5083-SrNSt	C	G5417	47.5	35.9	16.0	49.2**	32.3**	17.5**

CODE: Sr - Stretched
SrNSt - Stretched, not stabilized

*Supplied by Producers
**Determined at Frankford Arsenal

(U) Figure 2 shows a plot of fragment simulator hardness vs tempering temperature to be almost a linear relationship. Hardnesses were determined longitudinally and transversely on specimens sectioned at the center. No difference was observed between hardnesses at the center and at the surface. In the tempering for the Rc 21 to 23 simulators, some specimens were obtained that had hardnesses of Rc 15 to 16. These were also tested against three of the plates in order to extend the lower range of the investigation.

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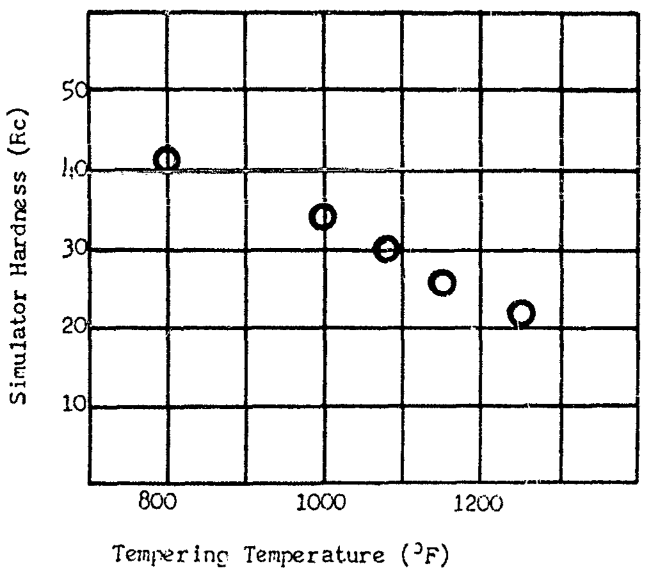


Figure 2. Tempering Temperature vs 20 mm Fragment Simulator Hardness

Armor Plates

(C) Aluminum-magnesium alloys 5456-H321 (supplied by Company A),* 5083-H115 and 5083-H118 stretched (supplied by Company B), and 5456-H322 and 5083-H113 (supplied by Company C), 1 1/4 in. thick, were used in these tests since they are the alloys being supplied for acceptance for fabrication of several T113 vehicles. Each plate was checked for thickness before testing. The mechanical properties (supplied by the producers) for the various plates are shown in Table III.

*See Code Sheet.

PROCEDURE

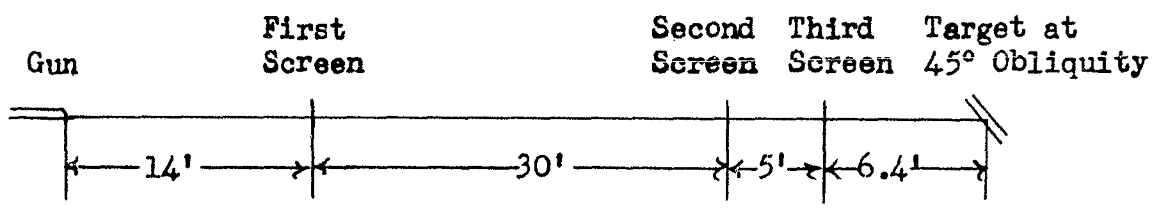
Target Conditions

(C) All firings were conducted at 45° obliquity because this was the specified ballistic acceptance obliquity for 1 1/4 in. thick plate when the program was started.

Firing

(U) The 20 mm fragment simulating projectiles were fired from Mann type barrels. Special cartridge cases were used for some of the firings to obtain high projectile velocities.

(U) The distance from the gun muzzle to the plate was 55 feet. Velocities at specified locations (as shown in the following diagram which presents the setup of the gun, velocity screens, and target) were obtained by means of chronographs actuated by breaking circuits printed on paper. Instrument velocities from the 30-ft and 5-ft base lines were corrected for retardation to obtain striking velocities.



Evaluation

(C) Protection ballistic limits* (PBL), in feet per second, were used for comparing the ballistic resistance of the aluminum-magnesium alloys against penetration by simulators of various hardnesses. The three lowest complete and the three highest partial penetrations within a spread of 150 fps were averaged for the PBL. Ballistic limits for plate thicknesses which deviated from 1 1/4 in. were corrected by assuming a linear relationship between ballistic limit and plate thickness.

*A protection-complete penetration is obtained when a fragment of the plate or projectile is ejected from the rear of the plate with sufficient energy to penetrate a 0.020 in. aluminum alloy (2024-T4) sheet, or its equivalent, placed parallel to and six inches behind the plate.

RESULTS AND DISCUSSION

(C) Results of firings of 20 mm fragment simulators of six hardnesses are summarized in Table IV and Figure 3. Several PBL's obtained with the simulators of Rc 15 to 16 hardness are also included.

(C) Figures 4, 5, and 6 show the PBL's that were obtained for the various simulator hardnesses on the individual armor plates. For some of the plates, rather large zones of mixed results (ZMR) were obtained; i. e., mixed partial and complete penetrations, with complete penetrations (CP) lower than partial penetrations(PP), were obtained in a velocity range larger than the 150 fps used to calculate the PBL. Since it was impractical to assign a PBL in these cases, the ZMR is indicated by two velocities (i. e., the highest PP and lowest CP) in Table IV and by two points connected by a vertical line in Figures 3 to 6, inclusive. Nevertheless, the velocity ranges in which the PBL's would be found or anticipated are similar to the velocities of the better defined limits.

(C) It may be noted that the PBL generally rises as the fragment simulator hardness is decreased, and vice versa. For simulators of Rc 21 to 23, the plate PBL's are 415 to 900 fps higher than for those of Rc 40 to 42; for simulators of Rc 15 to 16, the PBL's are 660 to 890 fps higher than for those of Rc 33 to 35. This is the result of a larger amount of simulator deformation on plate impact as the simulator hardness is reduced.

(C) Figure 7 shows that recovered fragment simulators of Rc 21 hardness deformed considerably more than those of Rc 30, while those of Rc 40 had no observable deformation after plate impact at PBL velocities. As they deform more, their impacting energy is distributed over a larger target area. This is also demonstrated in Figure 8, where the plugs ejected from the rear of a plate (Lot 791546) are larger for impacts by simulators of Rc 22 hardness than those of Rc 39 hardness when striking at PBL velocities. Softer simulators, therefore, require higher velocities to defeat the plate. For simulator hardnesses of Rc 33 to 35, very little deformation was observed after impact at PBL velocities.

(C) Figure 9 shows recovered simulators of Rc 21, 30, and 40 hardnesses after impacting at velocities of approximately 3100 fps on the same plate as the simulators shown in Figure 7. Figure 9 indicates that simulator deformation at constant velocity is at least a function of hardness. By comparing Figures 7 and 9 it may be noted that the extent of simulator deformation is a function of its hardness as well as its impacting velocity. This comparison also shows that plug size is dependent upon the extent of simulator

(C) TABLE IV. Protection Ballistic Limits of 1 1/4 in. Aluminum-Magnesium Plate vs 20 mm Fragment Simulator Hardness at 45° Obliquity

Alloy Plate					Protection Ballistic Limits (fps) at Simulator Hardnesses of Rc					
Type	Producer	Symbol	Lot No.	Thickness (in.)	15-16	21-23	25-27	29-31	33-35	40-42
5456-H321	A	○	180-661	1.233	-	2780	2720	2480-2695*	2375	2255
5456-H321	A	⊕	128-611	1.229	-	3035	-	2625	-	-
5083-H118-Sr	B	◒	791547	1.238	-	2790	-	2660	-	2300
5083-H118-Sr	B	◐	791546	1.270	-	2875	2590	2480	2470	2220
5083-Sr (8 3/4%)	B	◕	791936	1.311	-	2775-3020*	2590-2735*	2490-2750*	2390-2740*	2250
5083-H115	B	◑	740530	1.280	3040	2745	2490-2540*	2710	2380	-
5456-H322	C	□	GN7605(1)	1.275	>3135	-	-	2460	2380	-
5456-H322	C	◪	GN7605(2)	1.276	3170	-	-	-	2280	-
5083-H113	C	⬓	GN7711	1.276	-	3035-3215*	-	2780	-	2200
5083-SrNSt	C	◩	G5417	1.134	-	2445	2375	2100	-	2030
5083-H113	C	⬒	G7566	1.249	-	2970	-	-	2435	-

*Zone of mixed results

Code: Sr - Stretched
SrNSt - Stretched, not stabilized
(1) and (2) - Different plates of same lot

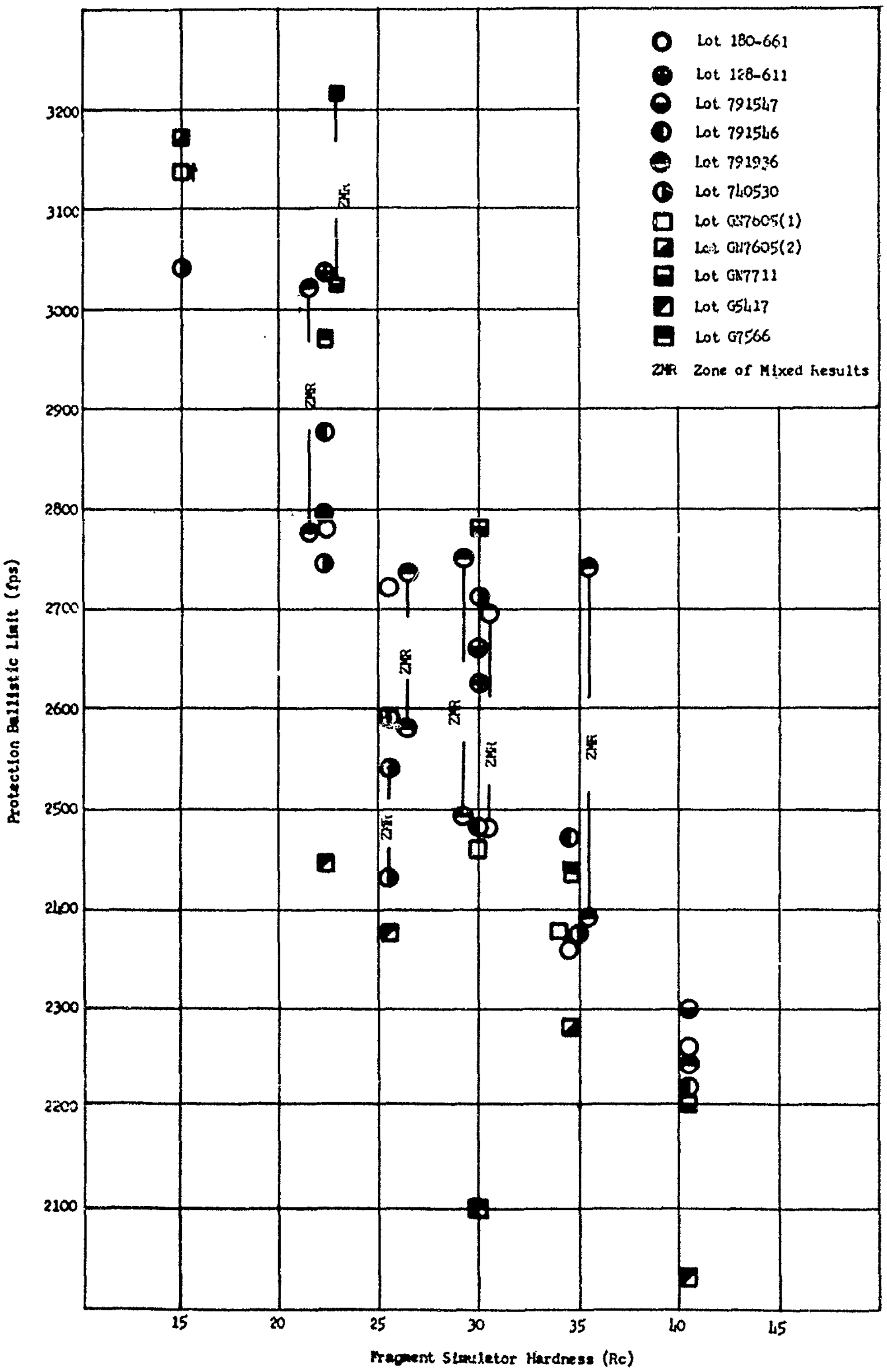


Figure 3. Plate Protection Ballistic Limit vs 20 mm Fragment Simulator Hardness for various 1 1/4 inch Aluminum-Magnesium Alloys at 45° Obliquity

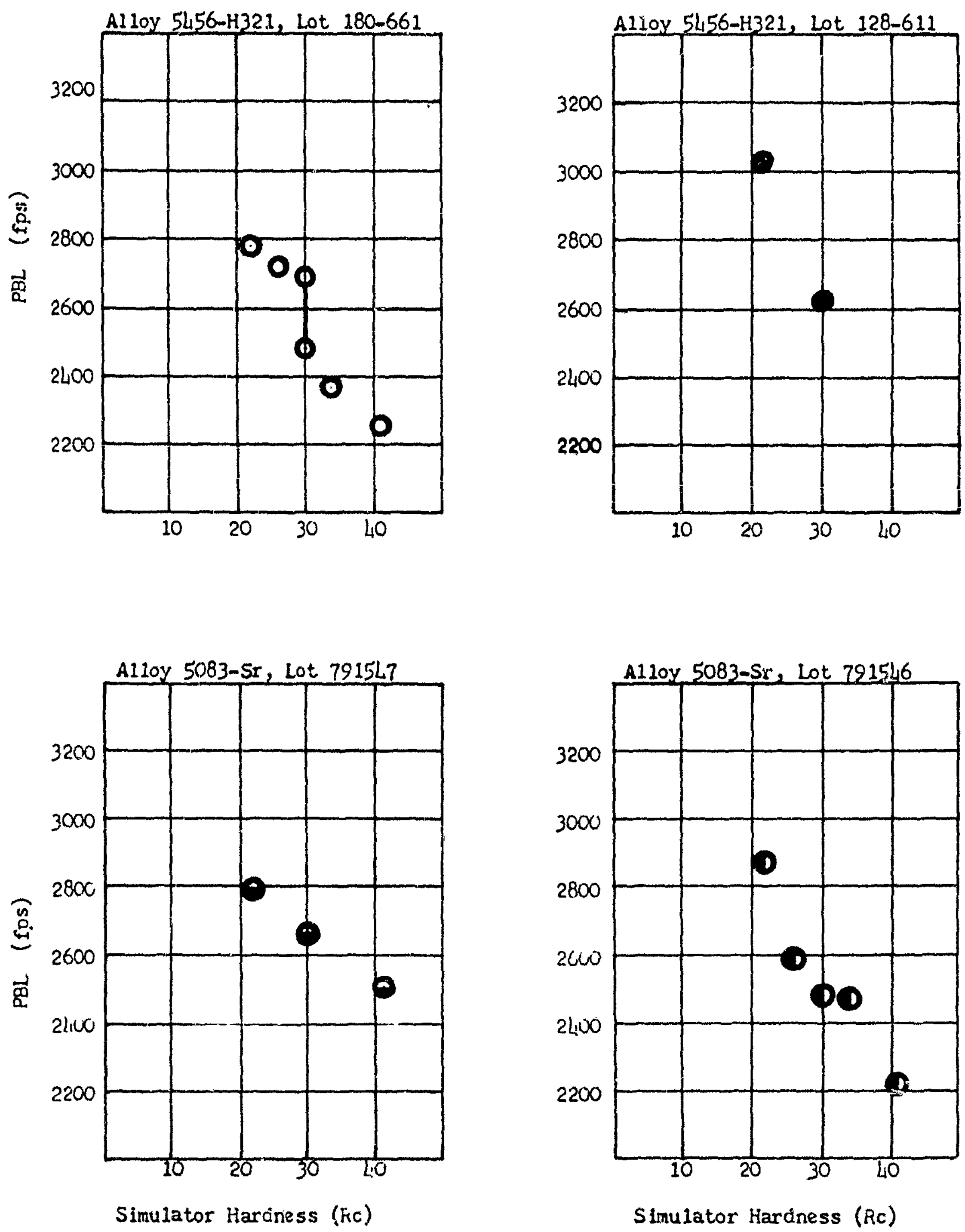


Figure 4. Plate Protection Ballistic Limit vs 20 mm Fragment Simulator Hardness for 1 1/4 inch Aluminum-Magnesium Alloys at 45° Obliquity

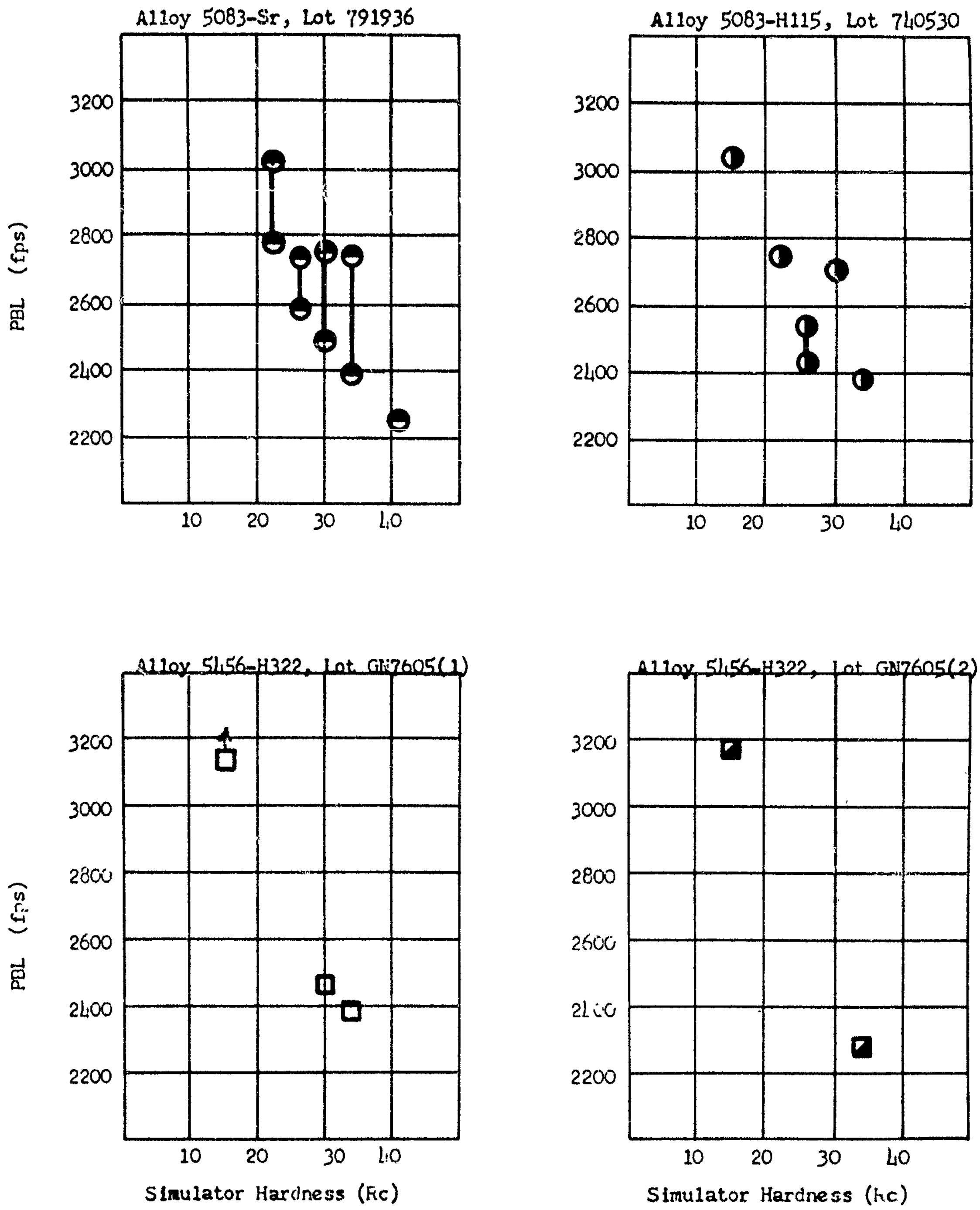


Figure 5. Plate Protection Ballistic Limit vs 20 mm Fragment Simulator Hardness for 1 1/4 inch Aluminum-Magnesium Alloys at 45° Obliquity

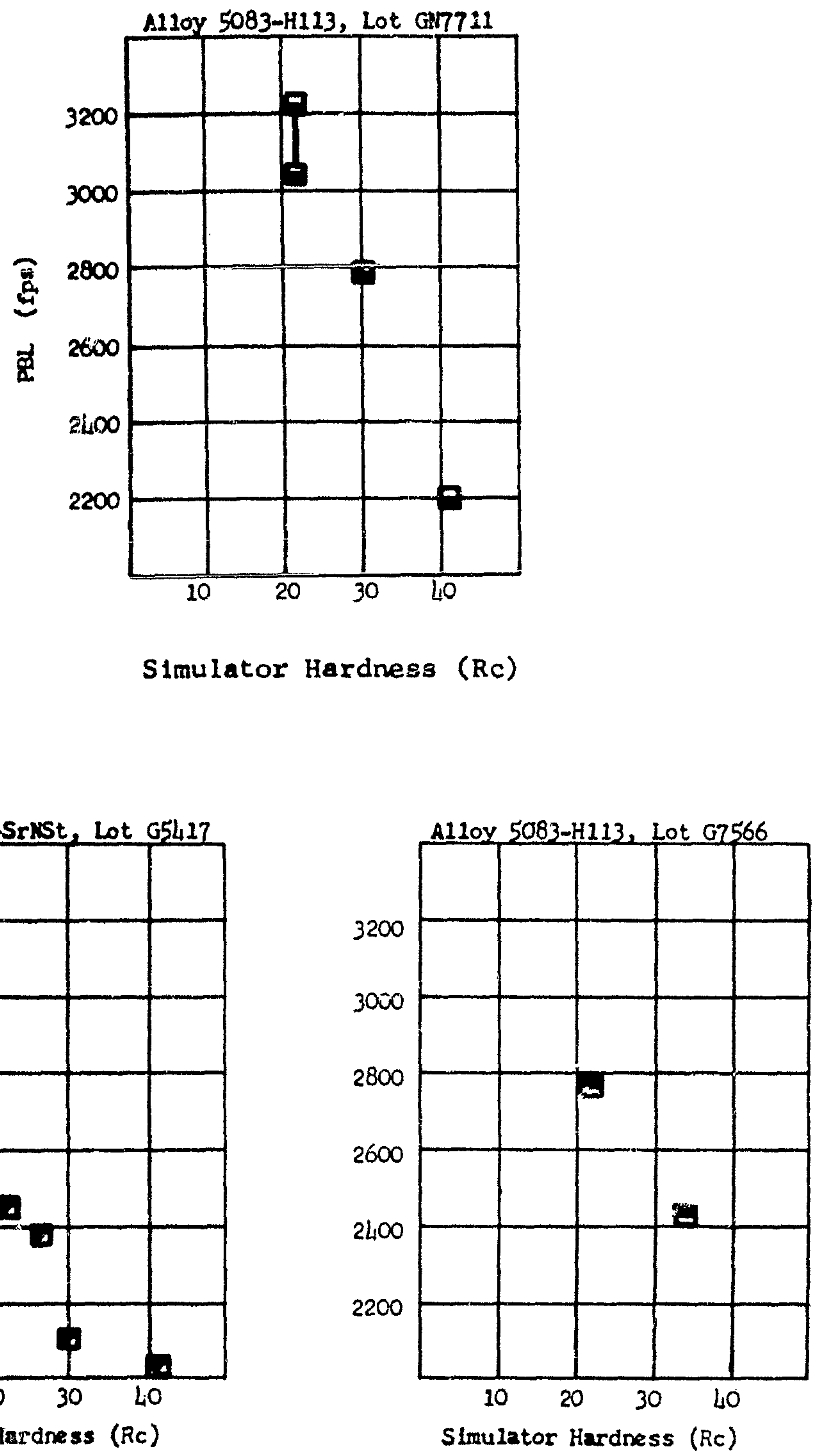
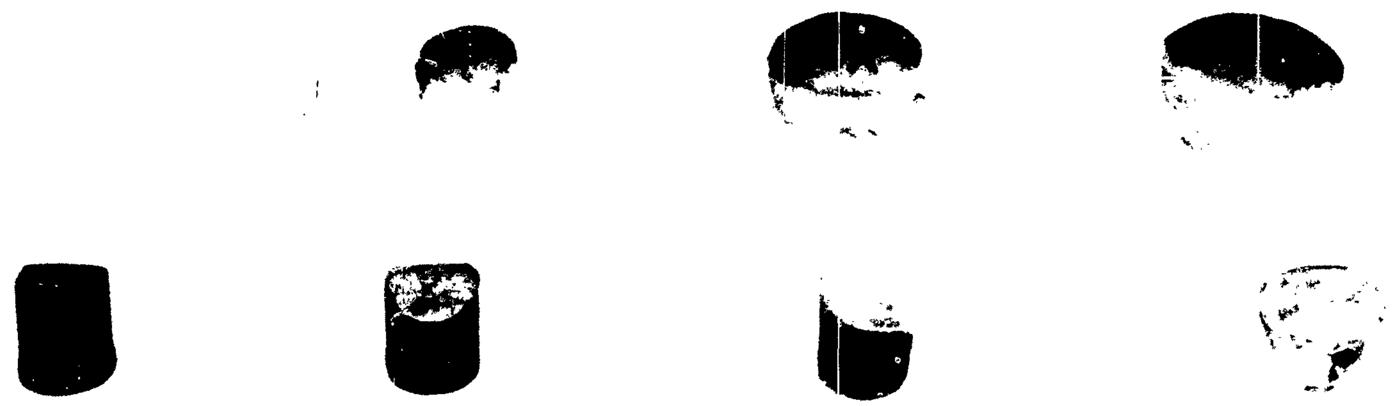
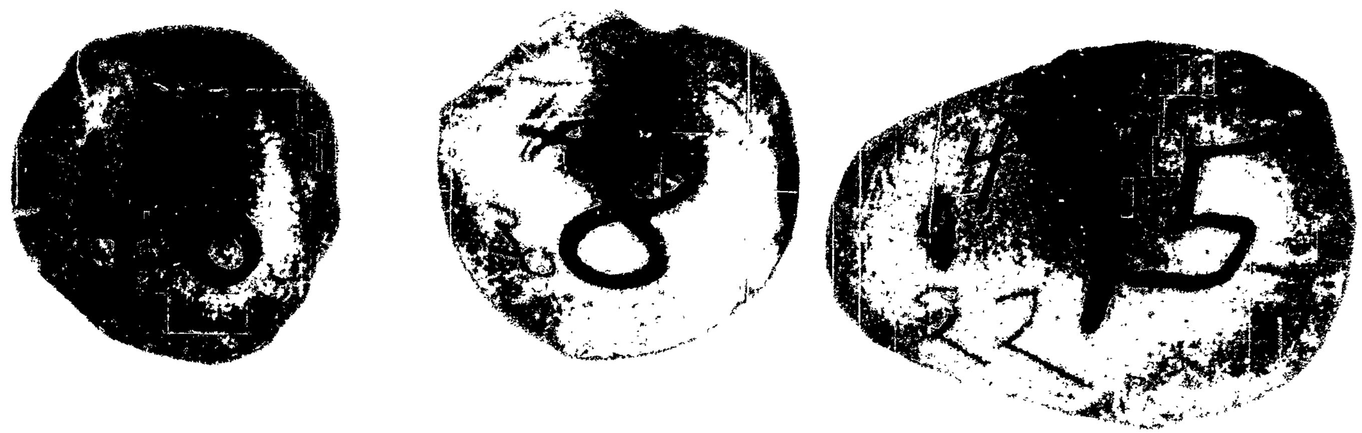


Figure 6. Plate Protection Ballistic Limit vs 20 mm Fragment Simulator Hardness for 1 1/4 inch Aluminum-Magnesium Alloys at 45° Obliquity



Not Fired | 40 Rc 2380 f/s | 30 Rc 2715 f/s | 21 Rc 3075 f/s

Figure 7. Variation of Plug Formation and Fragment Simulator Deformation vs Simulator Hardness at near PBL Velocity



Rc 39 Rc 30 Rc 22

Figure 8. Plate Plugs Recovered after Ejection by 20 mm Fragment Simulators of Rc 22, 30, and 39 Hardness Striking at PBL Velocities

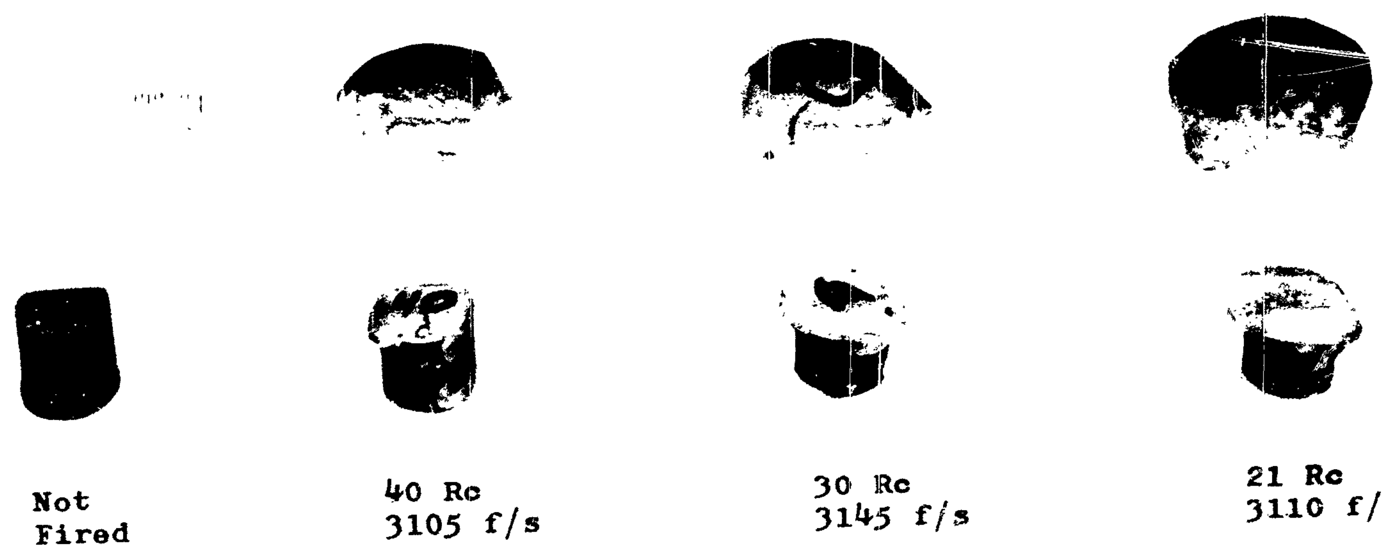


Figure 9. Variation of Plug Formation and Fragment Simulator Deformation vs Simulator Hardness at Constant Velocity

deformation. Since the hardest projectiles deformed only slightly, they required much less impacting energy or lower striking velocities than the softer projectiles to defeat the targets.

(C) It may be noted in Table IV and Figure 3 that the over-all spread in PBL's (with the exception of one) is less for Rc 41 simulators than for those of other hardnesses. Table IV and Figure 3 also show that the PBL's for plate lot G5417 are considerably lower than those of other plates for the various simulator hardnesses used. This accounts for some of the relatively large spread in over-all results for some of the fragment simulator hardnesses.

(C) From these results it can be seen that a difference of several points in simulator hardness on either side of the specified range (Rc 29 to 31) may result in significantly different ballistic limits. If these hardnesses are not carefully determined, and if those simulators having hardnesses outside of this range are not rejected, large errors in ballistic results may be obtained.

CONCLUSIONS

(C) If fragment simulators are used to evaluate the ballistic resistance of aluminum-magnesium alloys, variations in simulator hardness may produce significant differences in plate ballistic limits. Fragment simulator hardness is critical if simulators deform during target impact. If simulators do not deform, the plate ballistic limit is relatively independent of simulator hardness. Several points of variation in simulator hardness on either side of the specified range (Rc 29 to 31) may appreciably affect the PBL of 1 1/4 in. plate tested at 45° obliquity.

RECOMMENDATIONS

(U) It is recommended that the fabricators of fragment simulating projectiles be required to provide more uniform projectile lots so that 100 percent hardness check by the user is not necessary. This may be accomplished by using through-hardening steel and heat treating procedures which will assure minimum decarburization. If more than 5 per cent of a lot falls outside the specified hardness range during a hardness spot check, the entire lot should be rejected.

Until this practice is followed, fragment simulator hardness must be carefully determined before ballistic testing. Also, other ballistic test conditions should be investigated in order to minimize the zone of mixed results for armor acceptance purposes.

FUTURE WORK

(C) An investigation of the effect of fragment simulating projectile hardness on the ballistic resistance of aluminum-magnesium alloy armor will also be conducted for 20 mm simulators of various hardnesses against 1 1/4, 1 1/2, and 1 3/4 in. plates at 0° obliquity and for caliber .50 simulators of various hardnesses against 3/4 and 1 in. plates at 0° obliquity.

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2. Military Specification for "Aluminum Alloy Armor Plate, Weldable (U)," MIL-A-46027 (Ord), Supplement 1, 6 March 1959.